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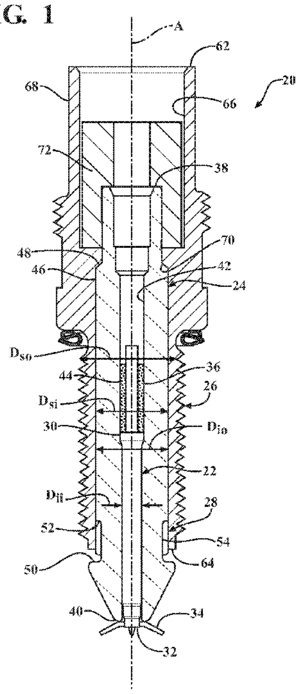
(54) Title: CORONA IGNITION DEVICE AND ASSEMBLY METHOD

FIG. 1



(57) Abstract: A reversed-assembled corona igniter including an insulator, central electrode, and metal shell, wherein an outer diameter of the insulator increases adjacent a lower end of the metal shell to achieve an electrical advantage is provided. In addition, the insulator maintains strength because is not placed under tension during or after assembly, or once disposed in an engine. To achieve the increase in insulator outer diameter, the insulator includes a lower shoulder adjacent the shell firing end. An intermediate part, such as braze and/or a metal ring, is disposed between the insulator outer surface and the shell adjacent the shell firing end. To prevent tension in the insulator, the insulator can be supported at only one location between the insulator upper end and the insulator lower end, for example along the intermediate part.

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CORONA IGNITION DEVICE AND ASSEMBLY METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. continuation-in-part patent application no. 15/240,502, filed August 18, 2016, the entire contents of which is hereby incorporated by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0002] This invention relates generally to a corona igniter for emitting a radio frequency electric field to ionize a fuel-air mixture and provide a corona discharge, and a method of forming the igniter.

2. Related Art

[0003] Corona discharge ignition systems include an igniter with a central electrode charged to a high radio frequency voltage potential, creating a strong radio frequency electric field in a combustion chamber. The electric field causes a portion of a mixture of fuel and air in the combustion chamber to ionize and begin dielectric breakdown, facilitating combustion of the fuel-air mixture. The electric field is preferably controlled so that the fuel-air mixture maintains dielectric properties and corona discharge occurs, also referred to as non-thermal plasma. The ionized portion of the fuel-air mixture forms a flame front which then becomes self-sustaining and combusts the remaining portion of the fuel-air mixture. Preferably, the electric field is controlled so that the fuel-air mixture does not lose all dielectric properties, which would create a thermal plasma and an electric arc between the electrode and grounded cylinder walls, piston, or other portion of the igniter. An example of a corona discharge ignition system is disclosed in U.S. Patent No. 6,883,507 to Freen.

[0004] The central electrode of the corona igniter is formed of an electrically conductive material for receiving the high radio frequency voltage and emitting the radio frequency electric field to ionize the fuel-air mixture and provide the corona discharge. The electrode typically includes a high voltage corona-enhancing electrode tip emitting the electrical field. The igniter also includes a shell formed of a metal material, and an insulator formed of an electrically insulating material disposed between the shell and the central electrode. The igniter of the corona discharge ignition system does not include any grounded electrode element intentionally placed in close proximity to a firing end of the central electrode. Rather, the ground is preferably provided by cylinder walls or a piston of the ignition system. An example of a corona igniter is disclosed in U.S. Patent Application Publication No. 2010/0083942 to Lykowski and Hampton.

[0005] During operation of high frequency corona igniters, there is an electrical advantage if the outer diameter of the insulator increases in a direction moving away from the grounded metal shell and towards the high voltage electrode tip. An example of this design is disclosed in U.S. Patent Application Publication No. 2012/0181916. For maximum benefit, it is often desirable to make the outer diameter of the insulator larger than the inner diameter of the grounded metal shell. This design has resulted in the need to assemble the igniter by inserting the insulator into the shell from the direction of the combustion chamber, referenced to as "reverse-assembly". However, the reverse-assembly method leads to a range of operational and manufacturing compromises which may be unacceptable. For example, when disposing the assembly in an internal combustion engine, it is difficult to retain the insulator in the shell without putting the insulator in tension. Typically, the tension in the insulator increases once the assembly is installed in the engine.

SUMMARY OF THE INVENTION

[0006] One aspect of the invention provides a reverse-assembled corona igniter for emitting a radio frequency electric field to ionize a fuel-air mixture and provide a corona discharge.

[0007] The corona igniter includes a central electrode formed of an electrically conductive material for receiving a high radio frequency voltage and emitting the radio frequency electric field. An insulator formed of an electrically insulating material surrounds a central electrode. The corona igniter is designed so that the insulator is not in tension during assembly or once installed in an engine. The insulator extends longitudinally from an insulator upper end to an insulator nose end. The insulator also includes an insulator outer surface extending from the insulator upper end to the insulator nose end, and the insulator outer surface presents an insulator outer diameter. The insulator outer surface includes an insulator lower shoulder extending outwardly and located between the insulator upper end and the insulator nose end, and the insulator lower shoulder presents an increase in the insulator outer diameter. A shell surrounds at least a portion of the insulator and extends from a shell upper end to a shell firing end. The shell presents a shell inner surface facing and extending along the insulator outer surface from the shell upper end to the shell firing end. The shell inner surface presents a shell inner diameter, and the shell inner diameter of at least one location of the shell is less than the insulator outer diameter at the insulator lower shoulder. An intermediate part formed of an electrically conductive material is disposed between the insulator outer surface and the shell inner surface and between the insulator upper end and the insulator lower shoulder.

[0008] A method of forming a corona igniter, specifically a reverse-assembly method, is also provided. The method includes providing an insulator formed of an electrically insulating material extending from an insulator upper end to and insulator nose end. The insulator includes an insulator outer surface extending from the insulator upper end to the insulator nose end and presents an insulator outer diameter. The insulator outer surface presents an insulator lower shoulder extending outwardly and located between the insulator upper end and the insulator nose end, and the insulator lower shoulder presents an increase in the insulator outer diameter. The method also includes providing a shell extending from a shell upper end to a shell firing end and including a shell inner surface presenting a shell bore. The shell inner surface presents a shell inner diameter, and the shell inner diameter of at least one location of the shell is less than the insulator outer diameter at the insulator lower shoulder. The method further includes inserting the insulator upper end into the shell bore through the shell firing end; and disposing an intermediate part formed of an electrically conductive material between the insulator outer surface and the shell inner surface.

[0009] The corona igniter of the present invention provides exceptional electrical performance because of the increased insulator outer diameter at the insulator lower shoulder. In addition, since the insulator remains not under tension, it can achieve a greater strength than insulators under tension.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Other advantages of the present invention will be readily appreciated, as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

[0011] Figures 1-8 are cross-sectional views of reverse-assembled corona igniters according to example embodiments wherein an insulator is in compression and no under tension;

[0012] Figures 9-16 are cross-sectional views of portions of corona igniters according to other example embodiments where an insulator is in compression and not under tension; and

[0013] Figure 17 is a cross-sectional view of another reverse-assembled corona igniter according an example embodiment wherein the insulator is not under compression or tension.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

[0014] Example embodiments of a reverse-assembled corona igniter **20** for receiving a high radio frequency voltage and emitting a radio frequency electric field to ionize a fuel-air mixture and provide a corona discharge in a combustion chamber of an internal combustion engine are shown in Figures 1-17. The corona igniter **20** includes a central electrode **22** receiving the high radio frequency voltage and emitting the radio frequency electric field, an insulator **24** surrounding the central electrode **22**, and a conductive component surrounding the insulator **24**. The conductive component includes a metal shell **26** and optionally includes an intermediate part **28**. In several embodiments, such as those of Figures 1-9, the conductive component and insulator **24** are arranged such that the insulator **24** is under compression to increase the strength of the insulator **24** compared to an insulator is placed in tension. In the embodiment of Figure 17, the insulator **24** is not under compression or tension, and thus also has an increased strength compared to an insulator placed in tension.

[0015] As shown in the Figures, the central electrode **22** of the corona igniter **20** extends longitudinally along a center axis **A** from a terminal end **30** to an electrode firing end **32**. The central electrode **22** is formed of an electrically conductive material for receiving the high radio frequency voltage, typically in the range of 20 to 75 KV peak/peak, and emitting the high radio frequency electric field, typically in the range of 0.8 to 1.2 MHz. In the example embodiments, the central electrode **22** includes a corona enhancing tip **34** at the electrode firing end **32**, for example a tip including a plurality of prongs, as shown in Figures 1-10 and 17. The terminal end **30** of the central electrode **22** is typically connected to an electrical terminal **36**, which is ultimately connected to an ignition coil (not shown). The ignition coil is connected to an energy source providing the high radio frequency voltage.

[0016] The insulator **24** of the corona igniter **20** also extends longitudinally along the center axis **A** from an insulator upper end **38** to an insulator nose end **40**. The insulator **24** typically surrounds the central electrode **22** such that the electrode firing end **32** is disposed outwardly of the insulator nose end **40**, as shown in Figures 1-10 and 17. An insulator inner surface **42** surrounds a bore receiving the central electrode **22**. A seal **44** is disposed in the bore around the electrical terminal **36** to secure the central electrode **22** to the electrical terminal **36**.

[0017] The insulator inner surface **42** presents an insulator inner diameter $\mathbf{D_{ii}}$ extending across and perpendicular to the center axis **A**. The insulator **24** also includes an insulator outer surface **46** extending from the insulator upper end **38** to the insulator nose end **40**. The insulator outer surface **46** presents an insulator outer diameter $\mathbf{D_{io}}$ extending across and perpendicular to the center axis **A**. The insulator inner diameter $\mathbf{D_{ii}}$ is preferably 15 to 40% of the insulator outer diameter $\mathbf{D_{io}}$.

[0018] In the embodiments of Figures 1-9, the insulator outer surface **46** presents an insulator upper shoulder **48** and an insulator lower shoulder **50** each located between the insulator upper end **38** and the insulator nose end **40** and each extending radially relative to the center axis **A**. Both the upper and lower insulator shoulders **48, 50** face toward the insulator upper end **38** and present an increase in the insulator outer diameter $\mathbf{D_{io}}$. The increase in insulator outer diameter $\mathbf{D_{io}}$ at the insulator lower shoulder **50** is typically greater than the increase at the insulator upper shoulder **48**, as shown in Figures 1-8. Alternatively, the increase in the insulator outer diameter $\mathbf{D_{io}}$ could be greater at the insulator lower shoulder **50**, as shown in Figure 9.

[0019] In the embodiment of Figure 17, the insulator **24** extends longitudinally from the insulator upper end **38** to the insulator upper shoulder **48** and then from the insulator upper shoulder **48** to the insulator lower shoulder **50**. In this embodiment, the insulator outer diameter $\mathbf{D_{io}}$ is constant from the insulator upper end **38** to the insulator upper shoulder **48**. The upper shoulder **48** presents an increase in the insulator outer diameter $\mathbf{D_{io}}$ in a direction moving from the insulator upper end **38** toward the insulator nose end **40**, such that the insulator outer diameter $\mathbf{D_{io}}$ is greater at the insulator upper shoulder **40** than at the insulator upper end **38**. The insulator outer diameter $\mathbf{D_{io}}$ is also constant from the insulator upper shoulder **48** to the insulator lower shoulder **50**. The insulator lower shoulder **50** presents another increase in the insulator outer diameter $\mathbf{D_{io}}$ in a direction moving from the insulator upper end **38** toward the insulator nose end **40**, such that the insulator outer diameter $\mathbf{D_{io}}$ is greater at the insulator lower shoulder **50** than at the insulator upper shoulder **48**. The insulator outer diameter $\mathbf{D_{io}}$ then decreases from the insulator lower shoulder **50** to the insulator nose end **40**. As will be discussed further below, the insulator **24** of this embodiment is supported in only one location, specifically in the location between the insulator upper shoulder **48** and the insulator lower shoulder **50**. Thus, the insulator **24** is not in tension or in compression during assembly, after assembly or once disposed in the engine.

[0020] In certain embodiments, as shown in Figures 1, 2 and 4-8, the insulator outer diameter $\mathbf{D_{io}}$ decreases (in a direction moving from the insulator upper end **38** toward the insulator nose end **40**) to present a middle ledge **52** located between the insulator upper shoulder **48** and the insulator lower shoulder **50**, before the insulator outer diameter $\mathbf{D_{io}}$ increases again at the insulator lower shoulder **50**. For example, the insulator **24** could include an insulator groove **54** between the middle ledge **52** and the insulator lower shoulder **50**. The insulator groove **54** can present a concave profile and can extend various lengths and depths. For example, the insulator groove **54** of Figures 1, 7, and 8 is longer than the insulator grooves **54** of Figures 2 and 4-6. In the embodiment of Figure 3, instead of the insulator groove **54**, the insulator outer surface **46** presents a plurality of ribs **56** with depressions **58** therebetween, as best shown in Figure 3A. The ribs **56** and depressions **58** are located adjacent the insulator lower shoulder **50**.

[0021] The insulator **24** can be formed of a single piece or multiple pieces of insulating material, such as alumina or another ceramic. In the embodiments of Figures 1-9, the insulator **24** is formed of a single piece of material. In the embodiments of Figures 10-12, however, the insulator **24** is formed of two pieces of material. The two pieces are typically press-fit and then further secured together using a glass seal **60**. In the embodiment of Figure 10, the central electrode **22** is positioned to support the insulator nose end **40**. In the embodiments of Figures 11 and 12, the second piece extending from the insulator upper end **38** toward the insulator nose end **40** can be provided as an outer mold or separate cap end.

[0022] The conductive component of the corona igniter **20** surrounds at least a portion of the insulator **24** such that an insulator nose region located adjacent the insulator nose end **40** extends outwardly of the conductive component, as shown in the Figures. The conductive component includes the shell **26** and may include the intermediate part **28**. The shell **26** and the intermediate part **28** can be formed of the same or different electrically conductive materials. For example, the shell **26** can be formed of steel and the intermediate part **28** can be formed of metal or metal alloy containing one or more of nickel, cobalt, iron, copper, tin, zinc, silver, and gold.

[0023] The shell **26** of the corona igniter **20** extends along the center axis **A** from a shell upper end **62** to a shell firing end **64**. The shell **26** presents a shell inner surface **66** facing the center axis **A** and extending along the insulator outer surface **46** from the shell upper end **62** to the shell firing end **64**. The shell **26** also includes a shell outer surface **68** facing opposite the shell inner surface **66** and presenting a shell outer diameter $\mathbf{D_{so}}$. The shell inner surface **66** presents a bore surrounding the center axis **A** and a shell inner diameter $\mathbf{D_{si}}$ extending across and perpendicular to the center axis **A**.

[0024] As shown in Figures 1-8 and 17, the shell inner surface **66** typically presents a shell upper shoulder **70** extending radially relative to the center axis **A** and located between the shell upper end **62** and the shell firing end **64**. The shell upper shoulder **70** engages the insulator upper shoulder **48** to help place the insulator **24** in compression, and thus increase the strength of the insulator **24**. In the embodiments of Figures 1-8, a flexible insulating element **72** is optionally disposed in the bore of the shell **26** above the shell upper shoulder **70** and surrounds the insulator upper end **38**.

[0025] As shown in Figures 1-8, the shell inner diameter $\mathbf{D_{si}}$ at the shell upper shoulder **70** is not greater than the insulator outer diameter $\mathbf{D_{io}}$ at the insulator upper shoulder **48**, and thus the corona igniter **20** is reverse-assembled. The term "reverse-assembled" means that the insulator upper end **38** is inserted into the bore of the shell **26** through the shell firing end **64**. Alternatively, the corona igniter **20** could be designed for forward-assembly. The term "forward-assembled" means that the insulator nose end **40** is inserted into the bore of the shell **26** through the shell upper end **62**.

[0026] In the embodiment of Figure 17, the shell inner diameter $\mathbf{D_{si}}$ increases slightly above the insulator upper shoulder **48** to present the shell upper shoulder **70** and then remains constant from the shell upper shoulder **70** to the shell firing end **64**. There is a gap located between the shell upper shoulder **48** and the insulator upper shoulder **48**. The shell inner diameter $\mathbf{D_{si}}$ at the shell firing end **64** is less than the insulator outer diameter $\mathbf{D_{io}}$ at the insulator lower shoulder **50**, and the shell firing end **64** rests on the insulator lower shoulder **50**. Thus, the corona igniter **20** of Figure 17 must be reverse-assembled, in which case the insulator upper end **38** is inserted into through the shell firing end **64** until the shell firing end **64** engages the insulator upper shoulder **48**.

[0027] In the embodiments of Figures 9 and 14, the shell **26** includes an upper turnover flange **74** at the shell upper end **62**, instead of the shell upper shoulder **70**. The upper turnover flange **74** extends radially inwardly toward the center axis **A** and engages the insulator upper shoulder **48** to help place the insulator **24** in compression, and thus increase the strength of the insulator **24**. In the embodiment of Figure 9, the shell outer surface **68** presents a pair of shell ribs **76, 77** located near the shell upper end **62,** and a notch **78** located adjacent the shell firing end **64**. The upper shell rib **76** is referred to as a hexagon, and the lower shell rib **77** is referred to as a gasket seat. The shell ribs **76, 77** are spaced from one another by a groove, and the lower shell rib **77** is disposed directly above a threaded region of the shell **26**. In this embodiment, the shell inner surface **66** presents a bead **80** located opposite the notch **78**. In the embodiment of Figure 14, a resin **82** is injection molded between the insulator **24** and upper turnover flange **74** of the shell **26**.

[0028] The shell **26** is also preferably designed with a groove **86** between the shell upper shoulder **70** and the shell firing end **64**. The groove **86** presents a reduced thickness along a portion of the shell **26**, which increases the flexibility of the shell **26**. When the corona igniter **20** is inserted into the internal combustion engine, the shell **26** is able to stretch without placing tension on the insulator **24**. Figures 15 and 16 show examples of reverse-assembled corona igniters **20** including the groove **86**. In the example embodiments, the groove **86** is formed along a portion of the shell inner surface **66** or along the shell inner surface **68** above a gasket seat **88**.

[0029] In addition to the upper turnover flange **74**, the conductive component can also include the intermediate part **28** adjacent the shell firing end **64**, as shown in Figures 1, 3, 6-8, 9, and 13 to help place the insulator **24** in compression. In the embodiment of Figure 1, the intermediate part **28** is a split steel sleeve disposed in the insulator groove **54**. In this embodiment, the intermediate part **28** engages the middle ledge **52** and is spaced from the insulator lower shoulder **50**. Alternatively, the intermediate part **28** could engage the insulator lower shoulder **50** instead of, or in addition to, the middle ledge **52**. The intermediate part **28** of Figure 1 is also welded or brazed to the insulator **24** and/or the shell **26** adjacent the shell firing end **64** by a layer of metal. In the embodiment of Figure 3, the intermediate part **28** is used to braze the insulator **24** to the shell **26** adjacent the insulator lower shoulder **50** and shell firing end **64**. As best shown in Figure 3A, the intermediate part **28** is a thin layer of metal disposed along the insulator ribs **56** and depressions **58**. The layer of metal is applied in liquid form and then solidifies between the insulator **24** and shell **26**. In the embodiment of Figure 6, the intermediate part **28** is a split ring gasket disposed against the middle ledge **52** of the insulator **24** and the shell firing end **64**. In the embodiment of Figure 7, the intermediate part **28** is a split or solid copper insert disposed between the middle ledge **52** and the shell firing end **64**. In the embodiment of Figure 8, the intermediate part **28** is a solid or split steel sleeve engaging the middle ledge **52** adjacent the shell firing end **64**. The steel sleeve is spaced from the insulator lower shoulder **50**, like the steel sleeve of Figure 1. In the embodiment of Figure 8, the steel sleeve is laser welded or soldered to the shell **26** and/or insulator **24**, for example by a silver solder. In the embodiment of Figure 9, the intermediate part **28** is a gasket or copper ring and engages the middle ledge **52** of the insulator **24**, and the insulator outer surface **46** is plated with metal along the insulator groove **54**. In the embodiment of Figure 13, the intermediate part **28** is formed of copper or a similar material and is press-fit against the insulator lower shoulder **50**. The intermediate part **28** may include a solid piece of material, and then an additional braze or solder is applied to the solid piece to secure the solid piece to the insulator **24** and the shell **26.** The intermediate part **28** of Figure 13 is also attached to the shell inner surface **66**, for example by brazing, welding, glue, solder, or press-fit.

[0030] In the embodiment of Figure 17, the intermediate part **28** is a layer of metal which secures or brazes the insulator **24** to the metal shell **26**. In the example embodiments, the metal contains one or more of nickel, cobalt, iron, copper, tin, zinc, silver, and gold. This layer of metal brazes the insulator **24** to the shell **26**.

[0031] In another example embodiment, the intermediate part **28** is formed from a solid piece of metal, specifically a solid ring formed of a silver (Ag) and/or copper (Cu) alloy disposed around the insulator **24**. Next, the shell **26** is disposed around the insulator **24**, and the assembly is heated at which time the solid ring, referred to as a braze, becomes liquid and is wicked into an area, referred to as a "braze area," through capillary action. As the parts cool, the liquid alloy solidifies to provide the intermediate part **28** brazed to the insulator **24** and to the shell **26**. This process puts the ceramic insulator **24** in compression because of the differences in shrinkage of the components after the alloy solidifies and as the parts cool. During operation, the engine temperature does not reach the melting point of the braze alloy used to form intermediate part **28**, so that it stays solid during engine operation. Alternatively, the intermediate part **28** could be formed by brazing the solid ring to the insulator **24** and shell **26** by another metal material, such as another metal having a lower melting point than the solid ring, using the brazing process described above.

[0032] In addition to, or instead of, the intermediate part **28**, the shell **26** can include a lower turnover flange **84** at the shell firing end **64**, as shown in Figures 2 and 4-7, to help place the insulator **24** in compression. In the embodiment of Figure 2, the lower turnover flange **84** is relatively thick and engages the middle ledge **52** of the insulator **24**. In this embodiment, there is no intermediate part **28** located between the middle ledge **52** and the lower turnover flange **84**, and the length of the insulator nose region is relatively long. In the embodiment of Figure 4, the lower turnover flange **84** is also relatively thick and engages the middle ledge **52** of the insulator **24**, but the length of the insulator nose region is shorter.

In the embodiment of Figure 5, the lower turnover flange **84** also engages the middle ledge **52** of the insulator **24**, with no intermediate part **28** therebetween. In this embodiment, the lower turnover flange **84** is bolder and thus slightly longer and thicker than in other embodiments. In the embodiment of Figures 6 and 7, the lower turnover flange **84** of the shell **26** engages a lower end of the intermediate part **28**. In each case wherein the shell **26** includes the lower turnover flange **84**, the shell firing end **64** is disposed in the insulator groove **54** and remains spaced from the insulator lower shoulder **50**. Alternatively, the shell firing end **64** could engage the insulator lower shoulder **50**.

[0033] As stated above, the shell upper shoulder **70** or upper turnover flange **74**, together with the groove **86**, intermediate part **28**, and/or lower turnover flange **84** of the embodiments of Figures 1-9 place the insulator **24** in compression therebetween. Typically, a compressive load ranging from 2 kN to 15 kN is placed on the insulator **24** prior to disposing the insulator **24** in an opening of the internal combustion engine, and the insulator **24** remains under compression even after being installed in the internal combustion engine. The mechanical strength of the insulator **24** under compression is higher than insulators placed under tension. For example, the strength of the insulator **24** typically ranges from 200 MPa to 600 MPa in tension and 3000 MPa to 4000 MPa in compression. Therefore, although the load placed on the insulator **24** after disposing the insulator **24** in the engine can range from compression to tension, it is desirable to keep the insulator **24** in compression during all aspects of the operating range. In the embodiment of Figure 17, the insulator **24** is supported or mechanically fixed to the shell **26** at only one location between the insulator lower shoulder **50** and the insulator upper shoulder **48** and thus is not in compression or tension during assembly or after installed in the engine. Accordingly, the insulator **24** of Figure 17 maintains exceptional strength.

[0034] Another aspect of the invention provides a method of manufacturing the reverse-assembled corona igniter **20** described above. The corona igniter **20** is typically reverse-assembled, in which case the method includes inserting the insulator upper end **38** through the shell firing end **64**. In the embodiments of Figures 1-8, the insulator upper shoulder **48** is pressed against the shell upper shoulder **70**. In the embodiment of Figure 17, the insulator **24** is inserted through the shell firing end **64** until the insulator lower shoulder **50** engages the shell firing end **64**. In the embodiments of Figures 9 and 14, the shell upper end **62** is bent inwardly toward the center axis **A** and over the insulator upper shoulder **48** to form the upper turnover flange **74** of the shell **26**. This step is conducted after disposing the insulator **24** in the shell **26**. In alternate embodiments, the corona igniter **20** can be designed for forward-assembly, in which case the method includes inserting the insulator nose end **40** into the shell upper end **62** before inserting the insulator upper end **38** through the shell upper end **62**.

[0035] To form the embodiments of Figures 1, 3, 6-9 and 13, wherein the corona igniter **20** includes the intermediate part **28**, the method includes securing the intermediate part **28** to the insulator **24** and/or shell **26** before or after disposing the insulator **24** in the shell **26**. For example, the method of forming the corona igniter **20** of Figure 1 can include simply placing the intermediate part **28** in the groove **54** of insulator **24**, and then inserting the intermediate part **28** and insulator **24** together through the lower end of the shell **26**. After the intermediate part **28** and insulator **24** are disposed in the shell **26**, the intermediate part **28** is fixed to the shell inner surface **66**, for example by brazing, welding, or press-fit. The method of forming the corona igniters **20** of Figures 6-8 can include brazing, soldering, or welding the intermediate part **28** to the insulator **24** before inserting the insulator **24** in the shell **26**, and then optionally brazing, soldering or welding the intermediate part **28** to the shell **26**. As discussed above, the intermediate part **28** can include a solid piece and then an additional braze to secure the solid piece to the insulator **24** and shell **26**. The method of forming the corona igniter **20** of Figure 3 includes securing the insulator **24** to the shell **26** using the intermediate part **28** after disposing the insulator **24** in the shell **26**. In this embodiment, the method includes applying the intermediate part **28** in a small gap between the insulator **24** and shell **26** in the form of a liquid metal and then allowing the liquid metal to solidify. Alternatively, the method can include applying the liquid metal to the insulator **24** immediately before inserting the insulator **24** into the shell **26**, and then allowing the liquid metal to solidify and braze the insulator **24** to the shell **26**.

[0036] To form the corona igniter **20** of Figures 1, 4, and 5, the method further includes bending the shell firing end **64** inwardly toward the center axis **A** against the insulator lower shoulder **50** to form the lower turnover flange **84** of the shell **26**. This step is conducted after disposing the insulator **24** in the shell **26**. Alternatively, the method can include bending the shell firing end **64** against the lower end of the intermediate part **28** to form the lower turnover flange **84**, as shown in Figures 6 and 8.

[0037] In the embodiment of Figure 17, the layer of metal in liquid form is applied between the insulator outer surface **46** and the shell inner surface **66**, and between the insulator lower shoulder **50** and the insulator upper shoulder **52** after the insulator **24** is inserted into the shell **26**. Typically, the metal is melted and flows into the small gap between the insulator **24** and shell **26**. The liquid metal is then allowed to cool and solidify to forming the intermediate part **28** which brazes the insulator **24** to the shell **26**.

[0038] Obviously, many modifications and variations of the present disclosure are possible in light of the above teachings and may be practiced otherwise than as specifically described while within the scope of the following claims. It is contemplated that all features of all claims and of all embodiments can be combined with each other, so long as such combinations would not contradict one another.

CLAIMS

1. A corona igniter for emitting a radio frequency electric field to ionize a fuel-air mixture and provide a corona discharge, comprising:

a central electrode formed of an electrically conductive material for receiving a high radio frequency voltage and emitting the radio frequency electric field;

an insulator formed of an electrically insulating material surrounding said central electrode and extending longitudinally from an insulator upper end to an insulator nose end;

said insulator including an insulator outer surface extending from said insulator upper end to said insulator nose end;

said insulator outer surface presenting an insulator outer diameter;

said insulator outer surface including an insulator lower shoulder extending outwardly and located between said insulator upper end and said insulator nose end;

said insulator lower shoulder presenting an increase in said insulator outer diameter;

a shell surrounding at least a portion of said insulator and extending from a shell upper end to a shell firing end;

said shell presenting a shell inner surface facing and extending along said insulator outer surface from said shell upper end to said shell firing end;

said shell inner surface presenting a shell inner diameter;

said shell inner diameter of at least one location of said shell being less than said insulator outer diameter at said insulator lower shoulder;

an intermediate part formed of an electrically conductive material disposed between said insulator outer surface and said shell inner surface and between said insulator upper end and said insulator lower shoulder.

2. The corona igniter of claim 1, wherein said insulator is supported only along said intermediate part so that said insulator is not in tension.

3. The corona igniter of claim 1, wherein said shell inner diameter at said shell firing end is less than said insulator outer diameter at said insulator lower shoulder;

4. The corona igniter of claim 1, wherein said intermediate part is a layer of metal securing said insulator outer surface to said shell inner surface.

5. The corona igniter of claim 4, wherein the layer of metal brazes the insulator outer surface to the shell inner surface.

6. The corona igniter of claim 1, wherein said intermediate part is a sleeve of metal extending circumferentially around said insulator.

7. The corona igniter of claim 6, wherein the intermediate part includes a layer of metal securing said sleeve of metal to said insulator outer surface and said shell inner surface.

8. The corona igniter of claim 1, wherein said insulator outer diameter decreases to present a middle ledge spaced from the increase in said insulator outer diameter at said insulator lower shoulder, said insulator includes a groove between said middle ledge and said insulator lower shoulder, and said intermediate part is disposed in said groove.

9. The corona igniter of claim 8, wherein said shell includes a lower turnover flange at said shell firing end, said lower turnover flange extends radially inwardly and into said

groove of said insulator, and said intermediate part is disposed in said groove between said lower turnover flange and said insulator outer surface.

10. The corona igniter of claim 9, wherein said lower turnover flange is bent around said middle ledge.

11. The corona igniter of claim 1, wherein said intermediate part is fixed to said insulator outer surface and said shell inner surface.

12. The corona igniter of claim 1, wherein said intermediate part is a layer of metal, and said insulator outer surface presents a plurality of ribs with depressions therebetween along said intermediate part.

13. The corona igniter of claim 1, wherein said intermediate part is spaced from said insulator lower shoulder.

14. The corona igniter of claim 1, wherein said central electrode includes a corona enhancing tip disposed outwardly of said insulator nose end and including a plurality of prongs extending radially outwardly.

15. The corona igniter of claim 1, wherein said insulator extends longitudinally from said insulator upper end to an insulator upper shoulder and from said insulator upper shoulder to said insulator lower shoulder;

said insulator upper shoulder presents an increase in said insulator outer diameter;

said insulator outer diameter is constant from said insulator upper end to said insulator upper shoulder;

said insulator outer diameter is greater at said insulator upper shoulder than at said insulator upper end;

said insulator outer diameter is greater at said insulator lower shoulder than said insulator upper shoulder;

said insulator outer diameter decreases from said insulator lower shoulder to said insulator nose end;

said insulator is supported only along said intermediate part so that said insulator is not in tension and not in compression;

said shell firing end engages said insulator lower shoulder;

said shell inner diameter at said shell firing end is less than said insulator outer diameter at said insulator lower shoulder;

said intermediate part is a layer of metal which secures said insulator to said metal shell, said metal contains one or more of nickel, cobalt, iron, copper, tin, zinc, silver, and gold;

said central electrode includes a corona enhancing tip disposed outwardly of said insulator nose end and including a plurality of prongs extending radially outwardly.

16. A method of forming a corona igniter, comprising the steps of:

providing an insulator formed of an electrically insulating material extending from an insulator upper end to and insulator nose end,

the insulator including an insulator outer surface extending from the insulator upper end to the insulator nose end and presenting an insulator outer diameter, the insulator outer surface presenting an insulator lower shoulder extending outwardly and located between the insulator upper end and the insulator nose end, the insulator lower shoulder presenting an increase in the insulator outer diameter;

providing a shell extending from a shell upper end to a shell firing end and including a shell inner surface presenting a shell bore, the shell inner surface presenting a shell inner diameter, the shell inner diameter of at least one location of the shell being less than the insulator outer diameter at the insulator lower shoulder;

inserting the insulator upper end into the shell bore through the shell firing end; and

disposing an intermediate part formed of an electrically conductive material between the insulator outer surface and the shell inner surface.

17. The method of claim 16, including supporting the insulator only along the intermediate part so the insulator is not in tension.

18. The method of claim 16, wherein the step of disposing the intermediate part between the insulator outer surface and the shell inner surface includes brazing the insulator outer surface to the shell inner surface.

19 The method of claim 16, wherein the step of disposing the intermediate part between the insulator outer surface and the shell inner surface includes disposing a solid piece of metal around the insulator, and brazing the solid piece of metal to the insulator outer surface and to the shell inner surface.

20. The method of claim 16 including engaging the shell firing end with the insulator lower shoulder.

21. The method of claim 16, wherein the insulator outer diameter decreases to present a middle ledge spaced from the insulator lower shoulder, the insulator includes a groove between the middle ledge and the insulator lower shoulder, and the step of disposing the intermediate part between the insulator outer surface and shell inner surface includes disposing the intermediate part in the groove.

22. The method of claim 20, wherein the shell includes a lower turnover flange at the shell firing end, and bending the lower turnover flange into the groove.

FIG. 1

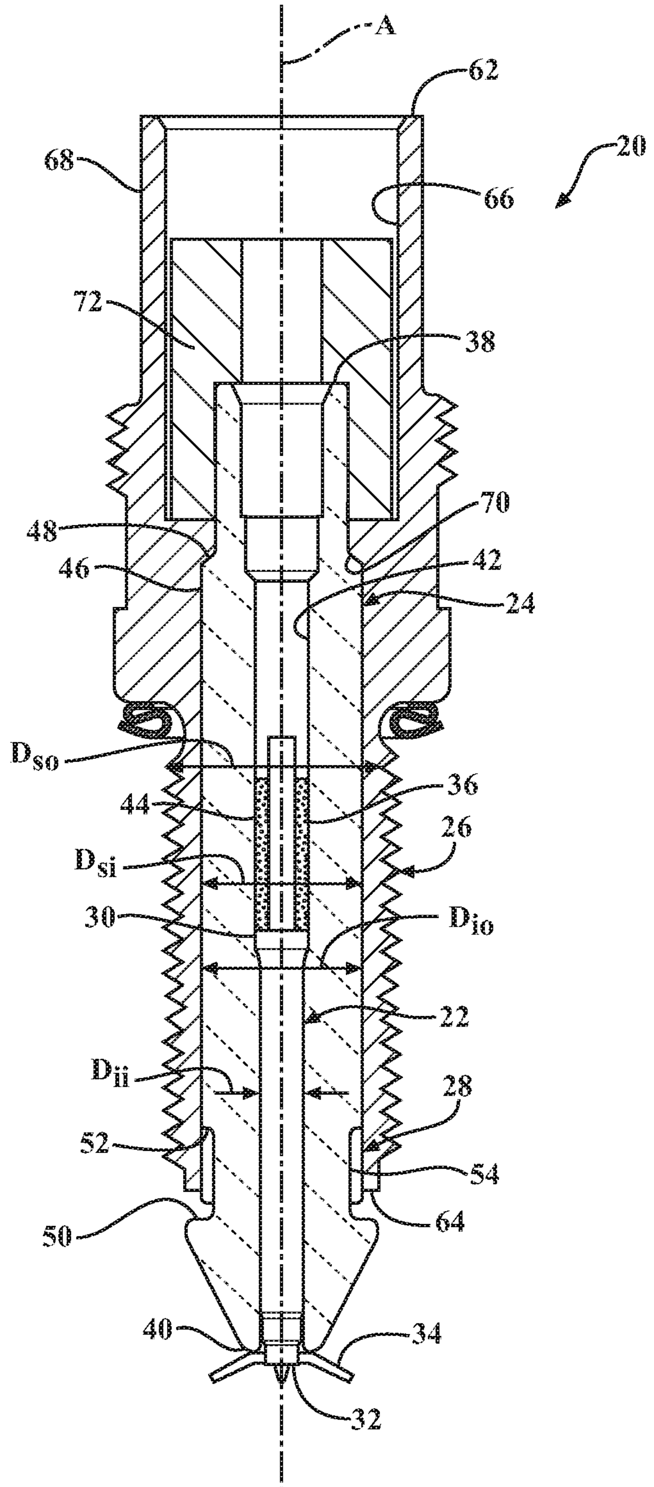
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FIG. 2

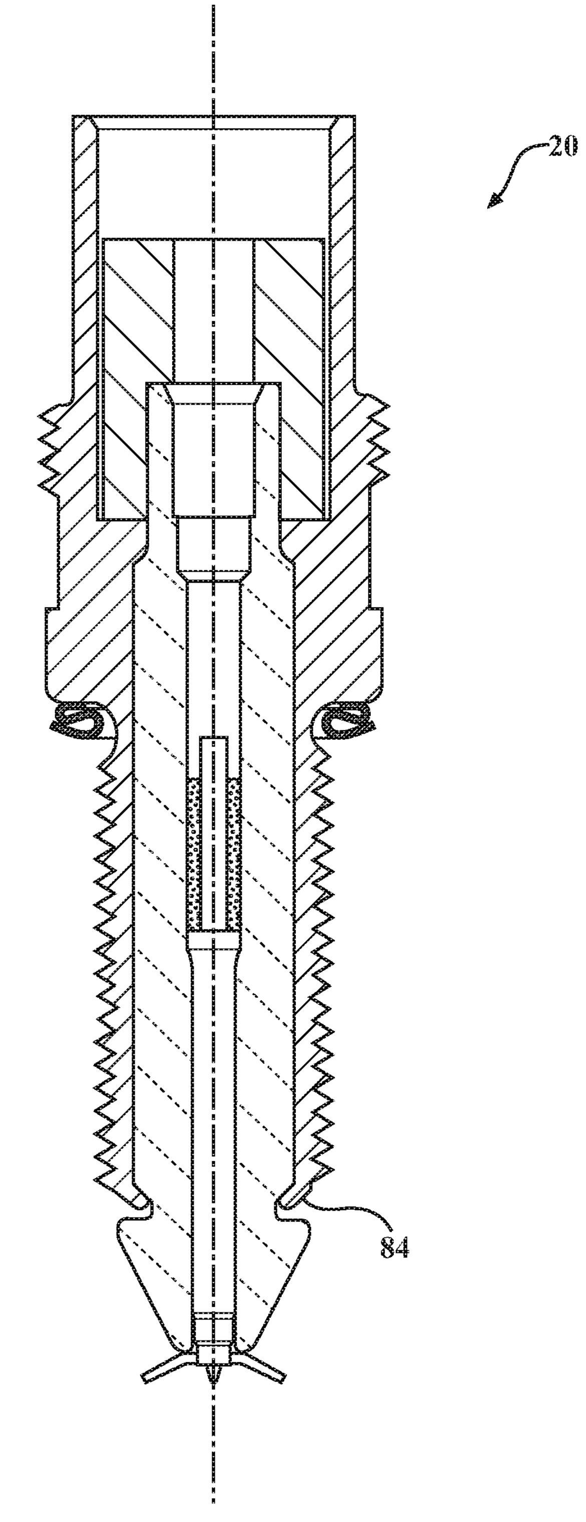


FIG. 3

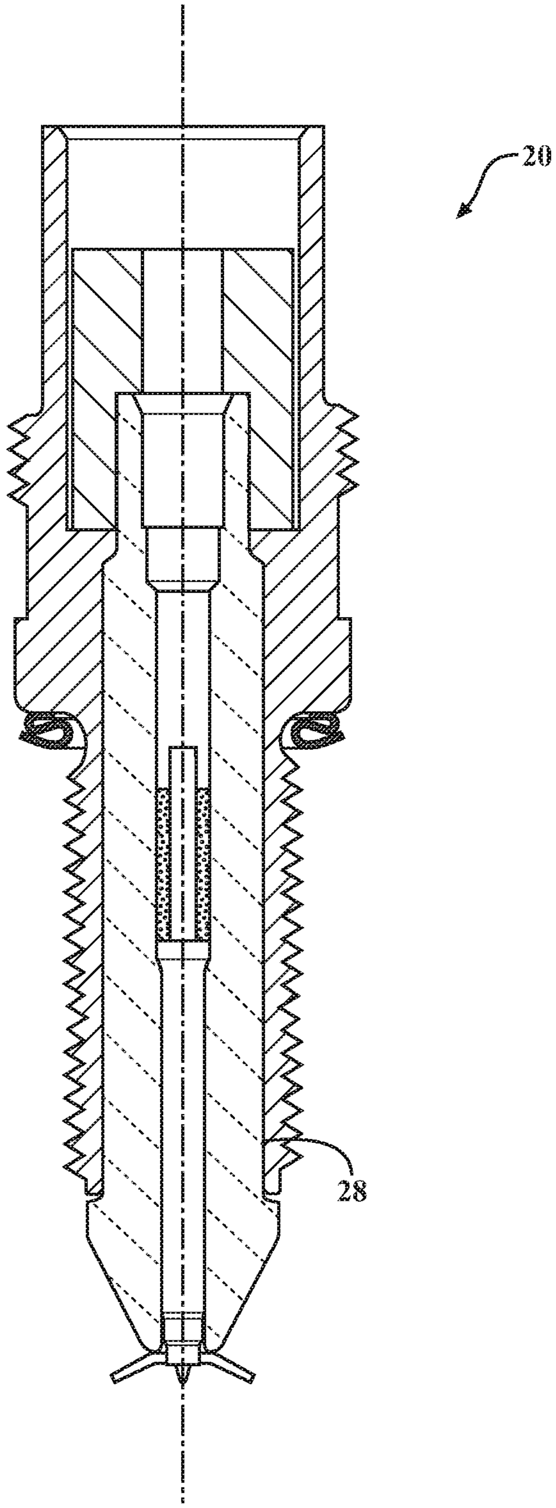


FIG. 3A

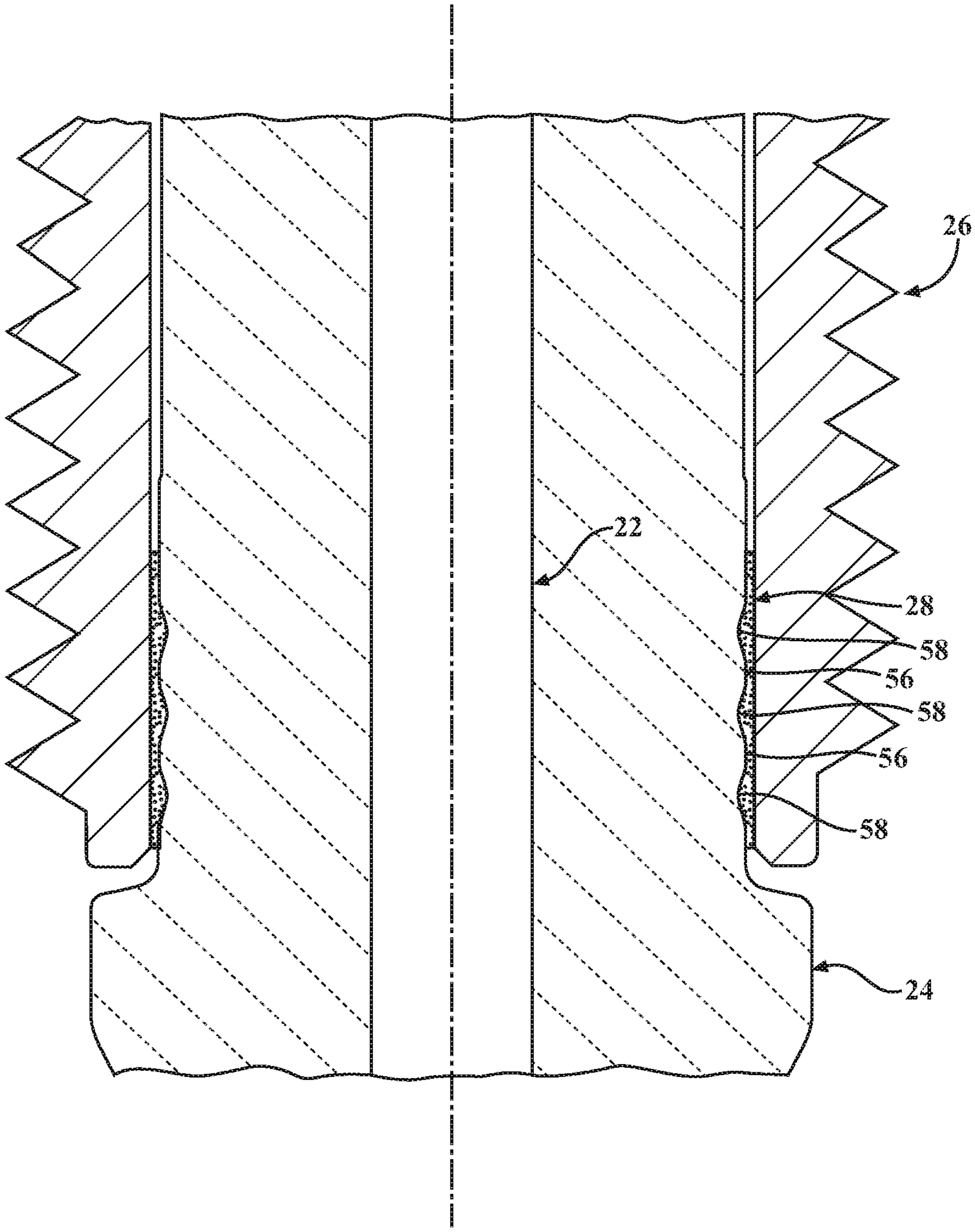


FIG. 4

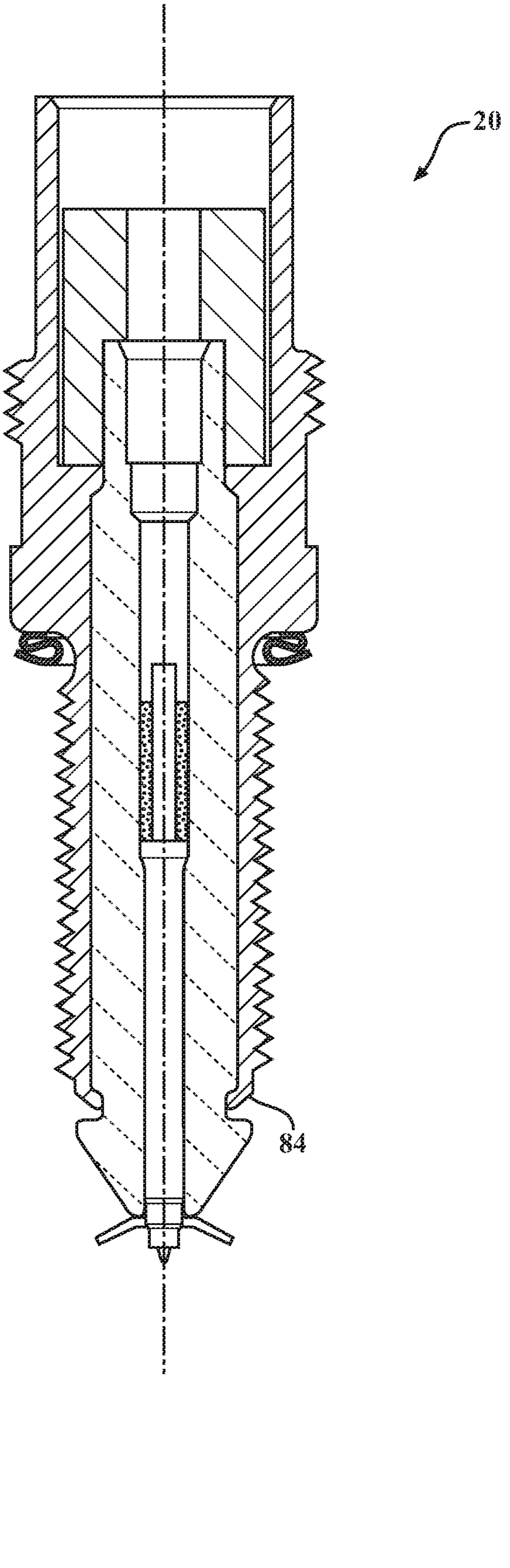


FIG. 5

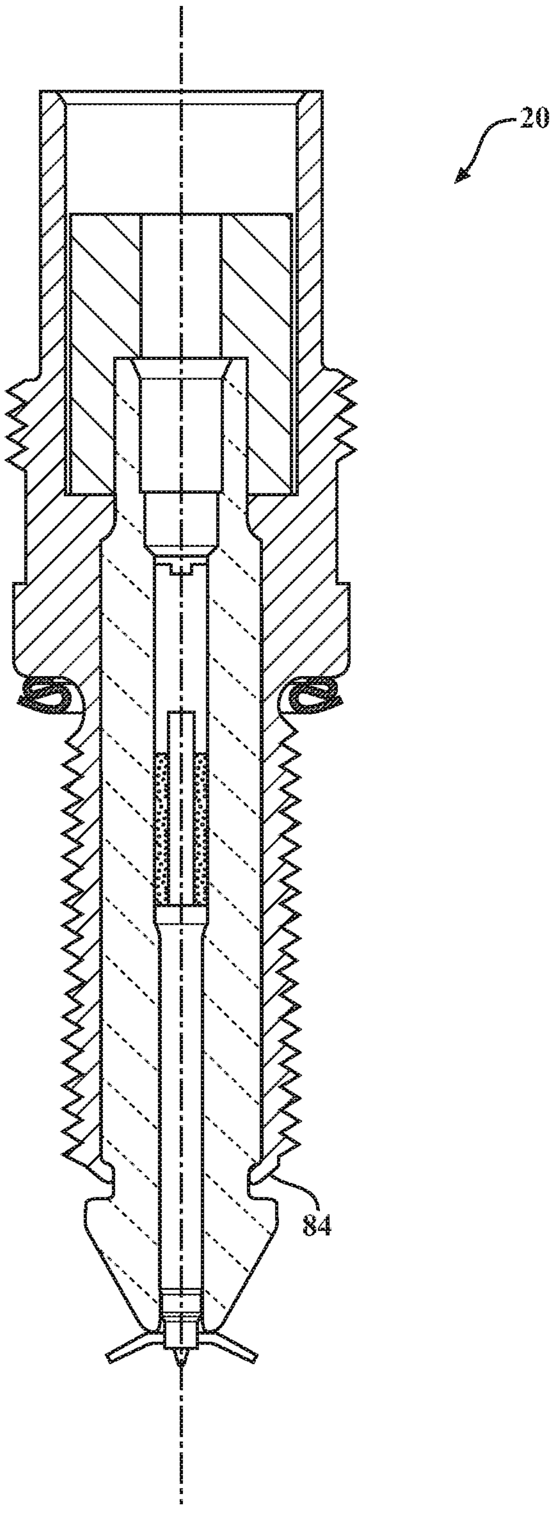


FIG. 6

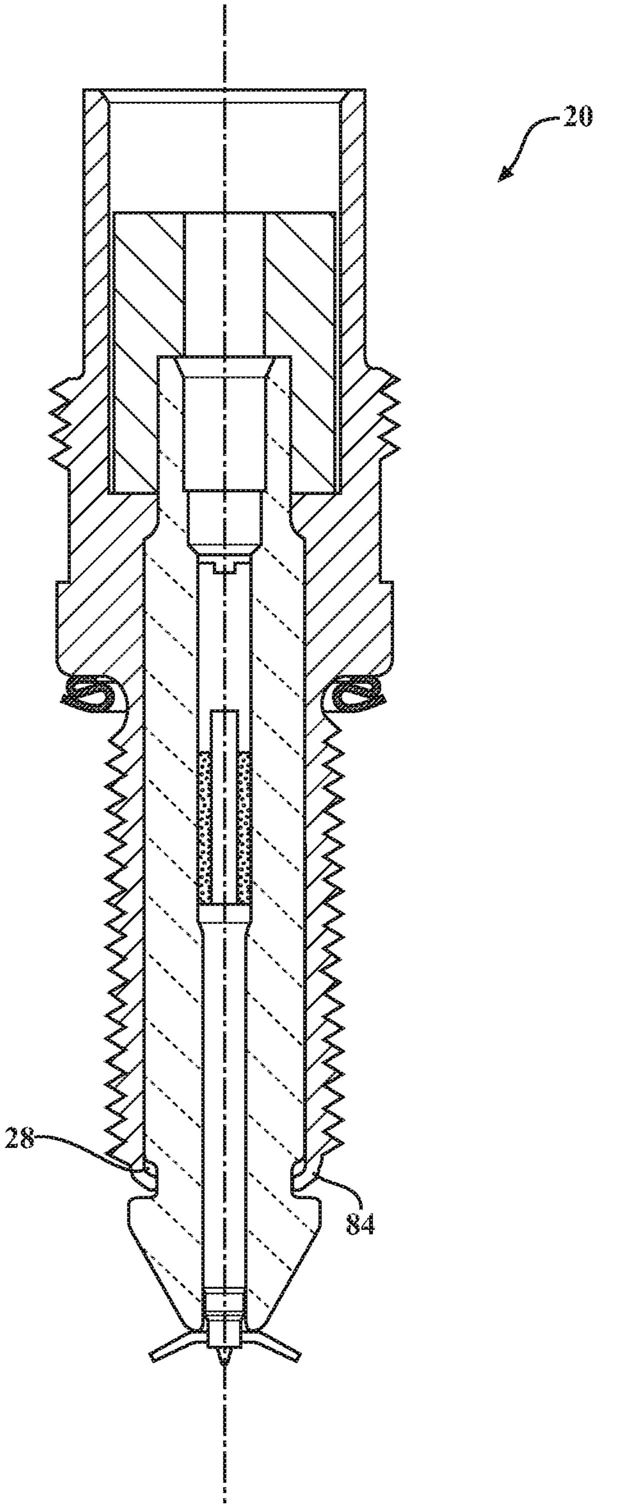


FIG. 7

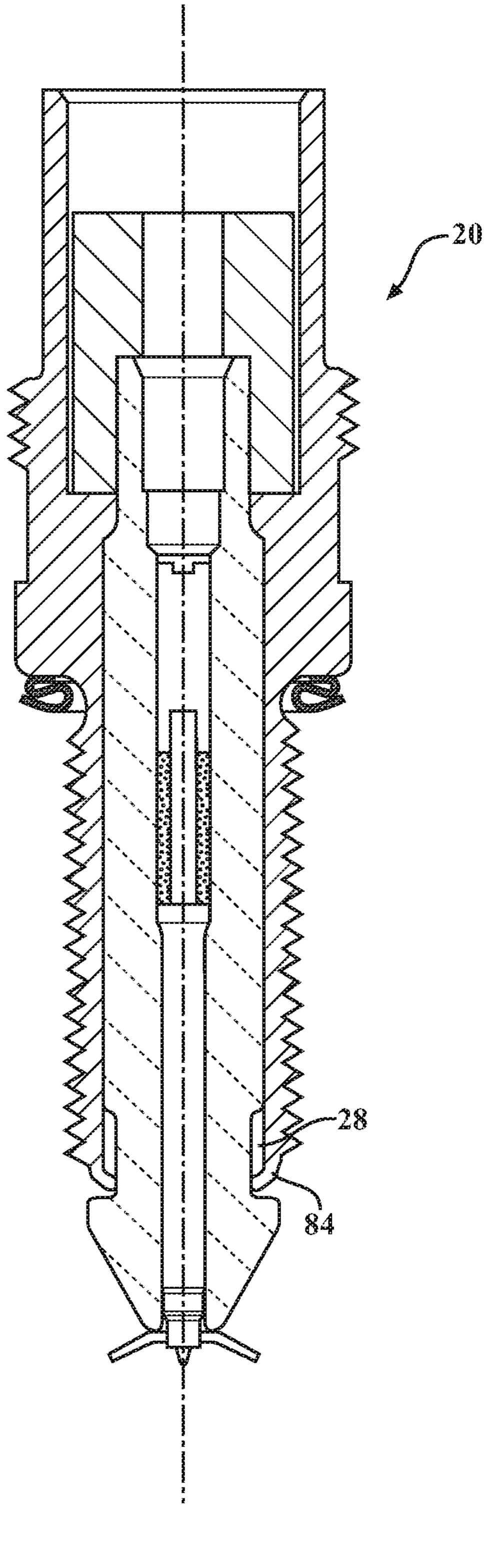
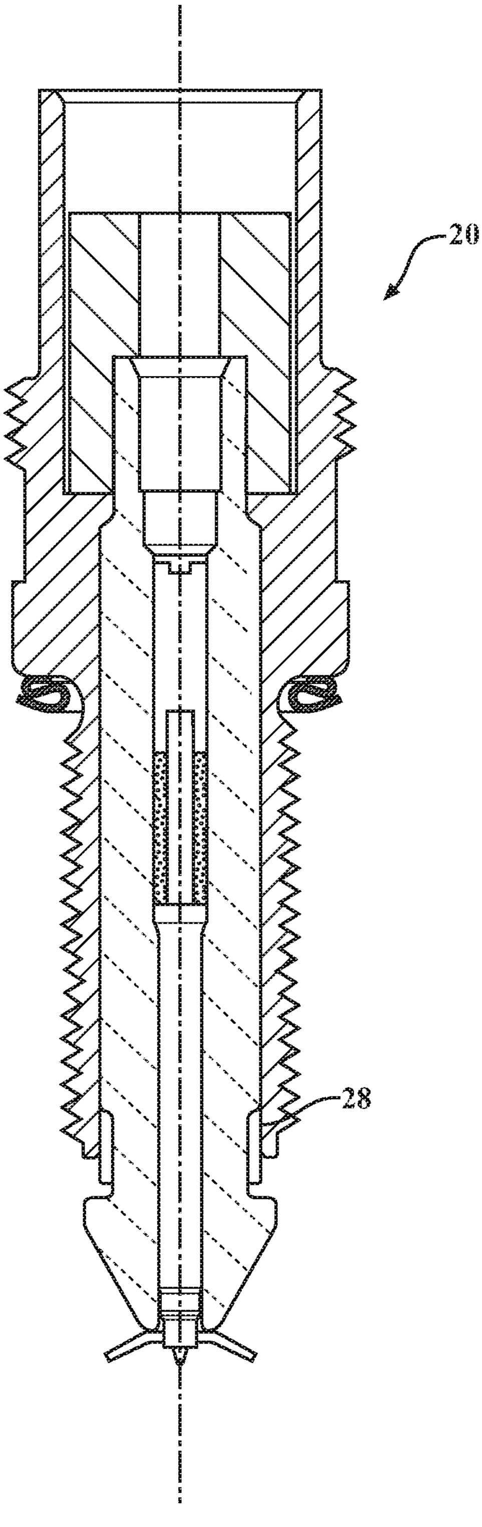


FIG. 8



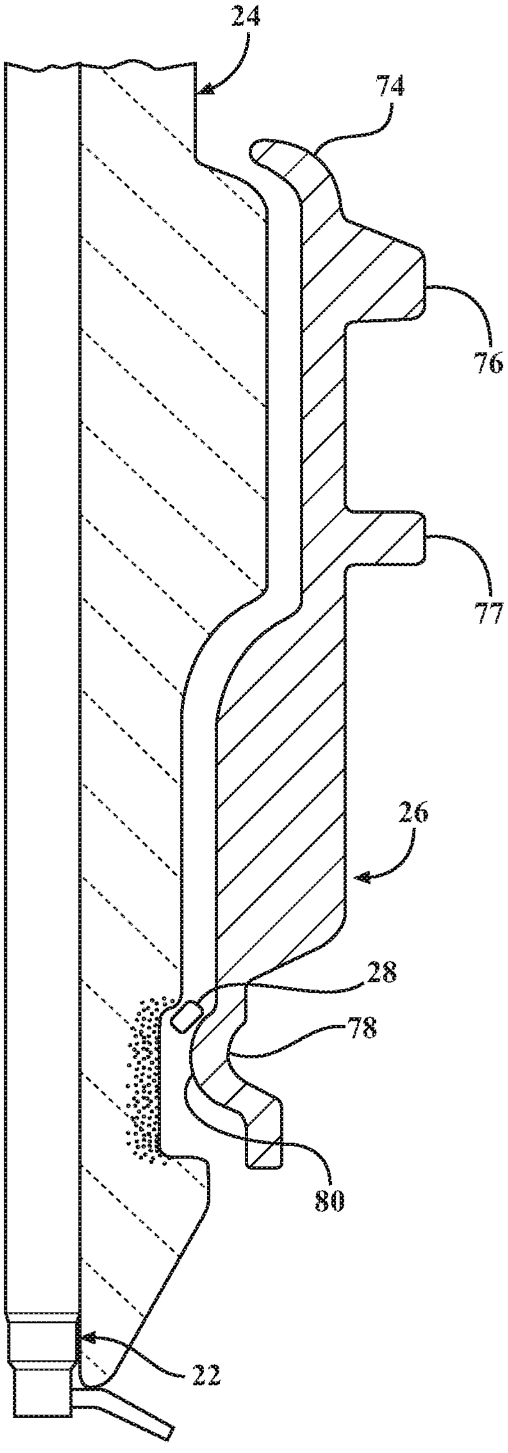


FIG. 9

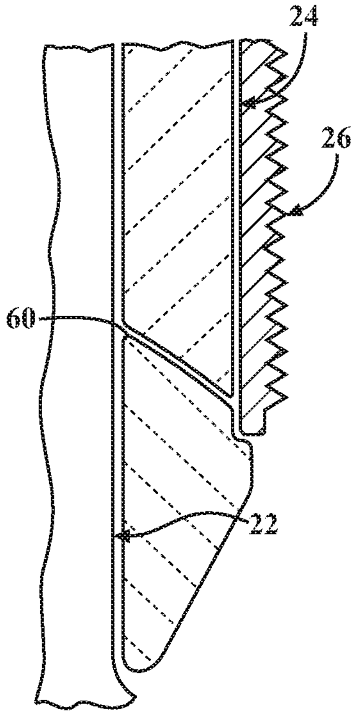


FIG. 10

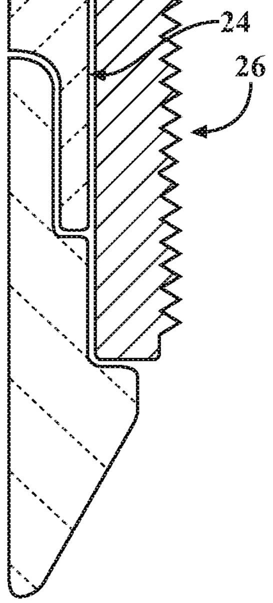


FIG. 11

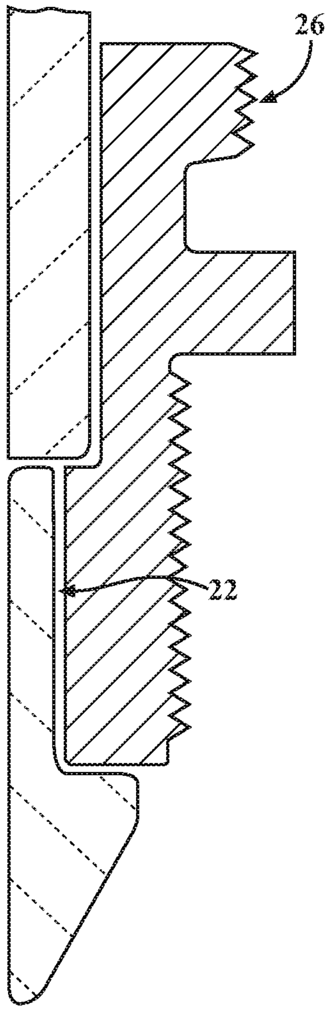


FIG. 12

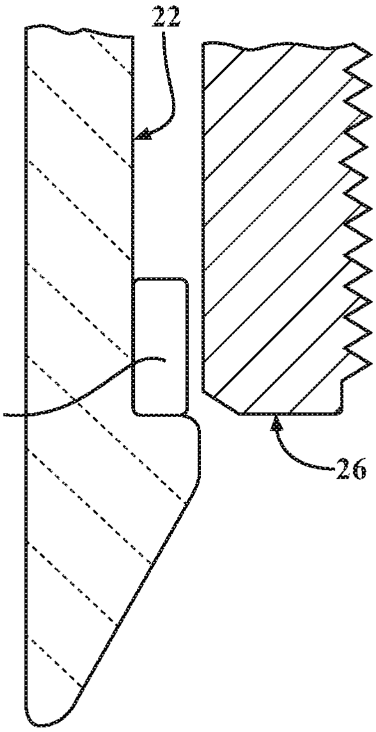


FIG. 13

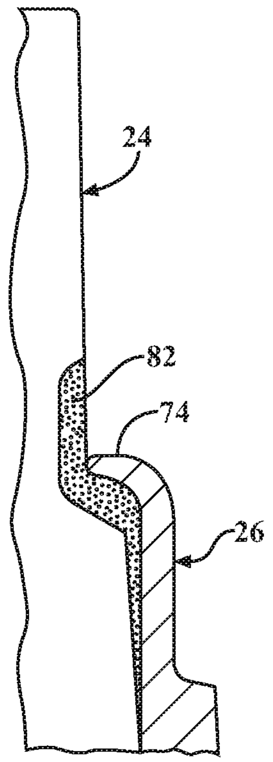


FIG. 14

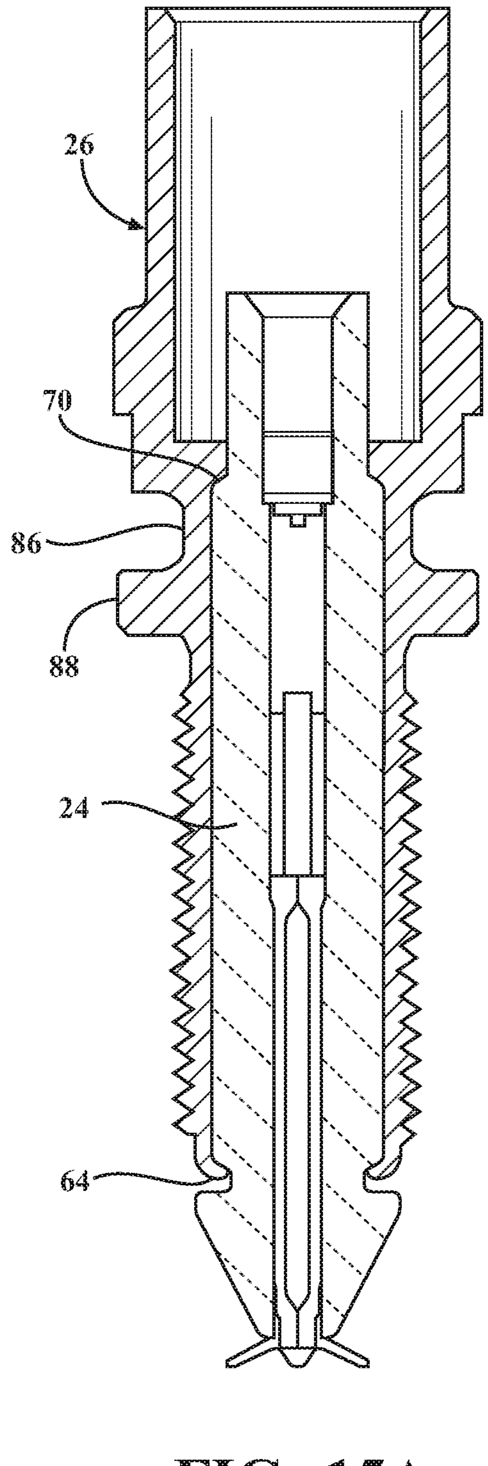


FIG. 15A

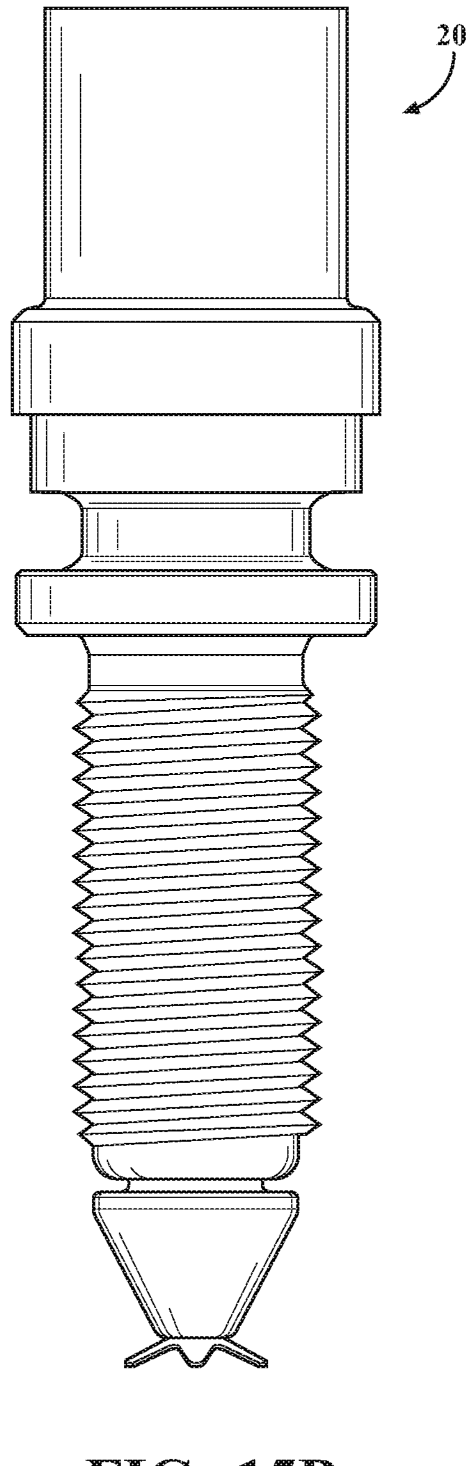


FIG. 15B

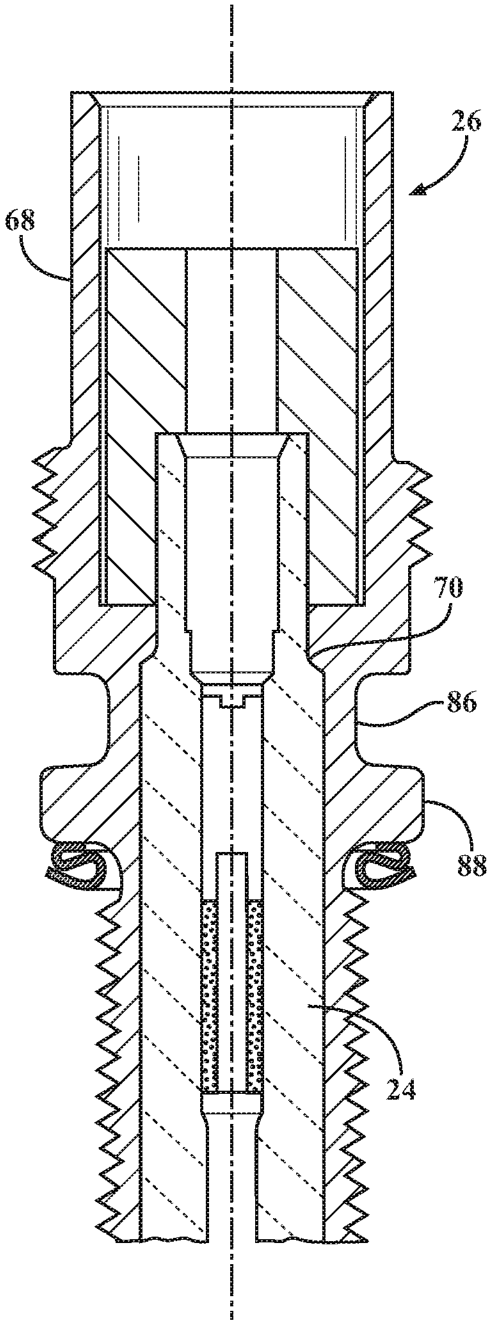


FIG. 16A

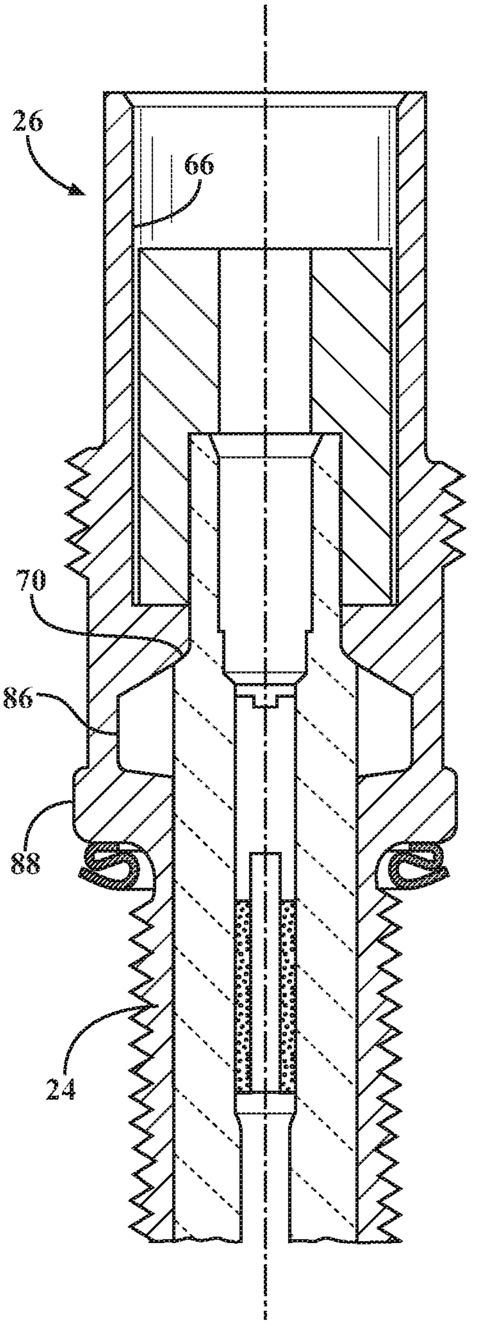


FIG. 16B

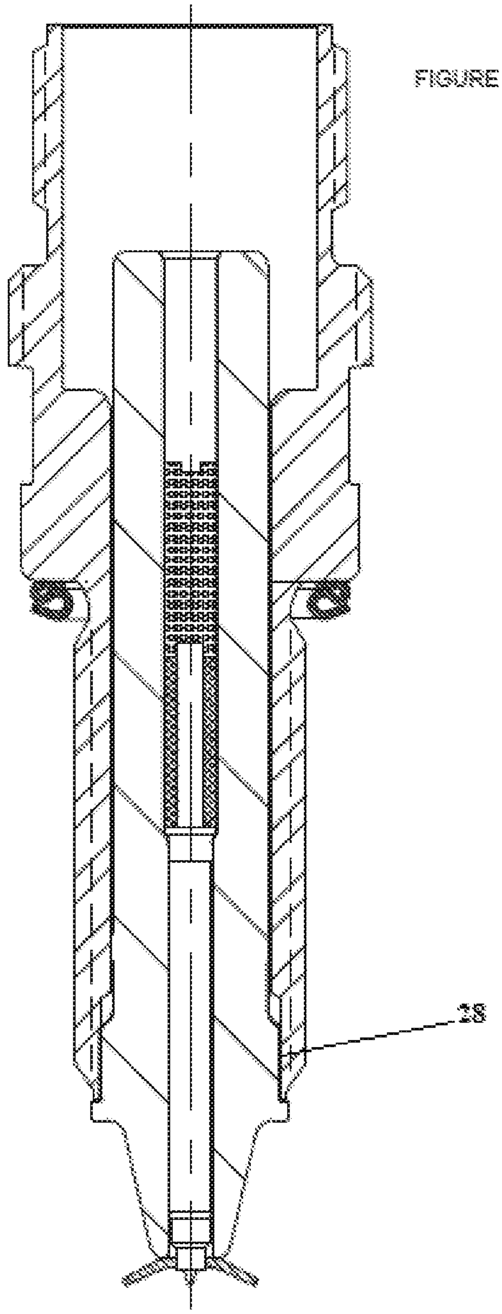


FIGURE 17

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/046344

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01T13/36 H01T13/38 H01T13/50 H01T21/02 H01T13/44
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01T

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2011/163654 A1 (MALEK NADIM [FR] ET AL) 7 July 2011 (2011-07-07)	1-7, 11-14, 16,18-20
A	paragraph [0019] - paragraph [0025]; figures 1-4	8-10,15, 17,21,22
X	DE 10 2014 111684 B3 (BORGWARNER LUDWIGSBURG GMBH [DE]) 1 October 2015 (2015-10-01)	1-7, 11-20
A	paragraph [0019] - paragraph [0024]; figure 2	8-10,21, 22
X	DE 10 2014 111897 A1 (BORGWARNER LUDWIGSBURG GMBH [DE]) 30 April 2015 (2015-04-30)	1-7, 11-20
A	paragraph [0034] - paragraph [0036]; figure 3	8-10,21, 22

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
7 November 2017	20/11/2017

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Ruppert, Christopher

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2010/083942 A1 (LYKOWSKI JAMES [US] ET AL) 8 April 2010 (2010-04-08) cited in the application abstract; figure 1 -----	14,15
A	US 2013/234581 A1 (MAKAROV MAXIME [FR] ET AL) 12 September 2013 (2013-09-12) figure 4 -----	10,22

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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PCT/US2017/046344

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